Reducing Children's Risk from Soil Lead: Summary of a Field Experiment

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ABSTRACT

Traditional methods for reducing risk from elevated levels of soil Pb involve removal, covering, or dilution by mixing with uncontaminated soil. Believing that *in situ* remediation techniques are viable alternatives, the EPA's National Risk Management Research Laboratory (NRMRL) and DuPont Corporation established a collaborative effort to evaluate *in situ* remediation technologies. Reductions in Pb bioavailability (*in vivo* and *in vitro*) and changes in Pb geochemistry observed as a result of *in situ* treatment demonstrate that reduction in soil Pb risk can be accomplished without soil removal.

INTRODUCTION

Lead (Pb) poisoning is the most common and most serious environmental disease affecting young children, according to the Centers for Disease Control and Prevention (CDC). The CDC estimates that Pb poisoning in children costs billions of dollars in medical and special education expenses and decreased future earnings. Lead paint, Pb in drinking water, and Pb in soil and dust are the major remaining sources of exposure (Figure 1).

Lead, a naturally occurring metal, has always been present in soils, surface waters and ground waters. Flaking paint, decades of leaded gasoline use, mining operations, smelter and industrial emissions, waste incineration, and application of pesticides all contributed to elevated Pb levels in soils. To complicate matters, Pb usually remains near the surface of the soil where it is deposited - increasing the chance of exposure.

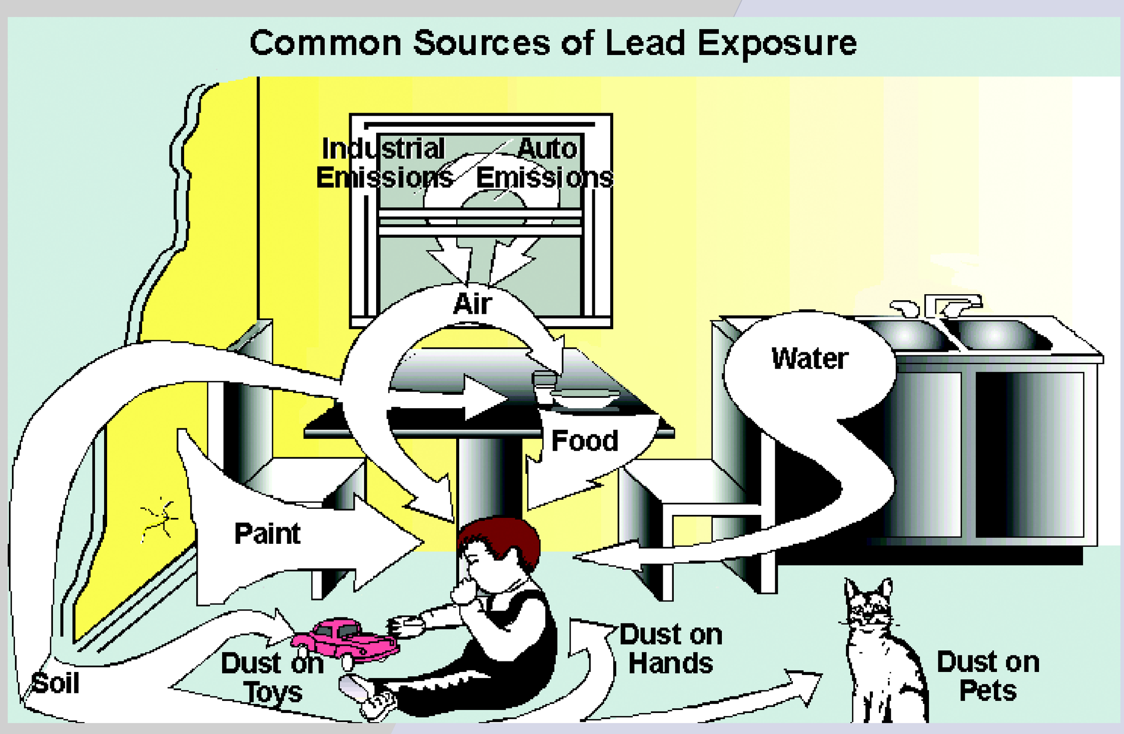

Figure 1. Sources of lead exposure to children (adapted from (51))

REDUCING EXPOSURE

Techniques to reducing exposure generally focus on blocking the pathway to the human receptors. Cost, logistical concerns, and regulatory requirements associated with excavation, *ex situ* treatment and disposal, however, can make in situ treatment an attractive option. If the soil Pb forms are converted to Pb forms that have reduced bioavailability, the overall bioavailability of Pb in the soil should be reduced. Based upon these understandings the US EPA's National Risk Management Research Laboratory (NRMRL) started a research program to demonstrate the connection among soil Pb mineralogy, soil chemistry, and soil Pb bioavailability (1) (Figure 2).

Laboratory Studies

Lead is rapidly and effectively precipitated from solution by orthophosphate (aqueous P, hydroxyapatite, or phosphate rock) to form a series of Pb phosphates of low aqueous solubilities (1). The final product of Pb immobilization is primarily pyromorphite [$Pb_5(PO_4)_3X$, where X is OH, Cl or F], which is stable under normal environmental conditions. The completeness and kinetics of this transformation have been found to depend upon the Pb mineral, amount of apatite added and the pH of the system.

Field Studies

As it became apparent that soil Pb mineralogy could easily be altered under laboratory conditions, NRMRL, in cooperation with the DuPont Co, formed the In-place Inactivation & Natural Ecological Restoration Technologies (IINERT) Soil-Metals Action Team to provide a forum to explore and develop these *in situ* techniques. The IINERT group established a field experiment to focus and facilitate collaborative efforts as well as test the hypothesis that addition of materials to Pb contaminated soils will induce the formation of less hazardous Pb forms.

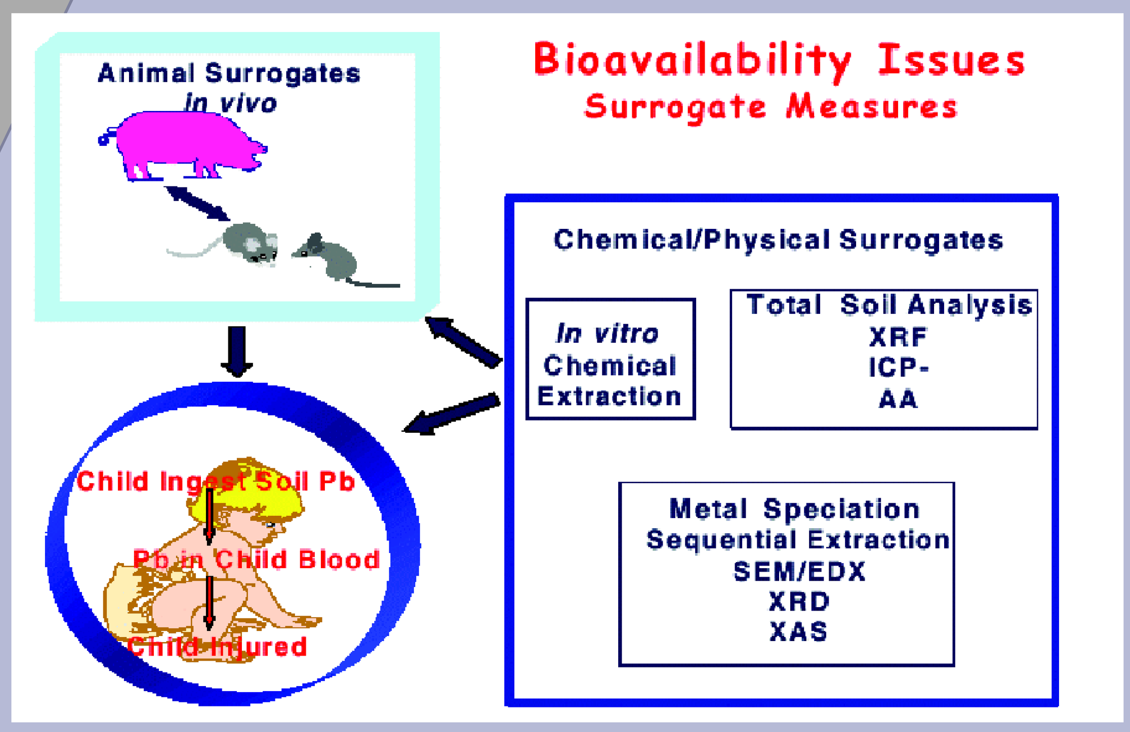

Figure 2. Fundamental issues addressed by IINERT

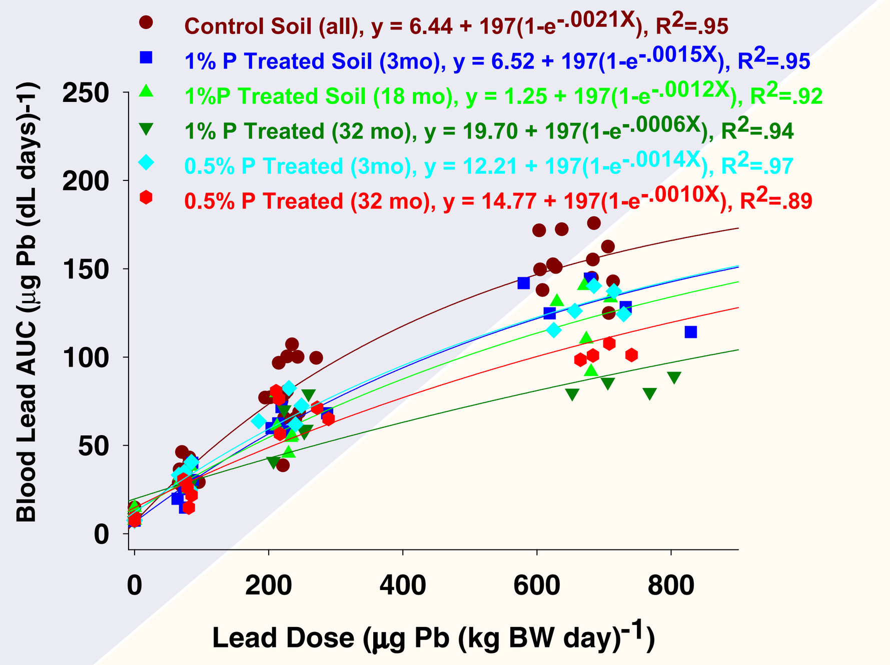

Figure 3. Swine blood lead response as a function of *in situ* phosphorus treatment and time after treatment of a lead contaminated soil.

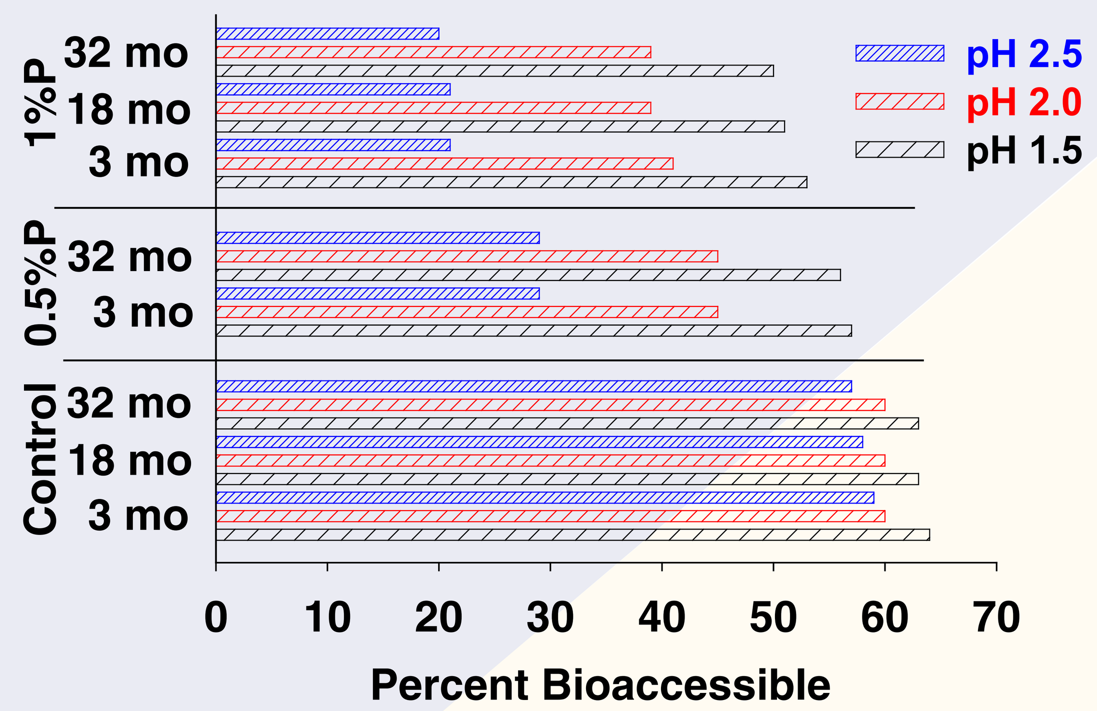

Figure 4. *In vitro* bioaccessible lead as a function of *in situ* phosphorus treatment and time after treatment of a lead contaminated soil.

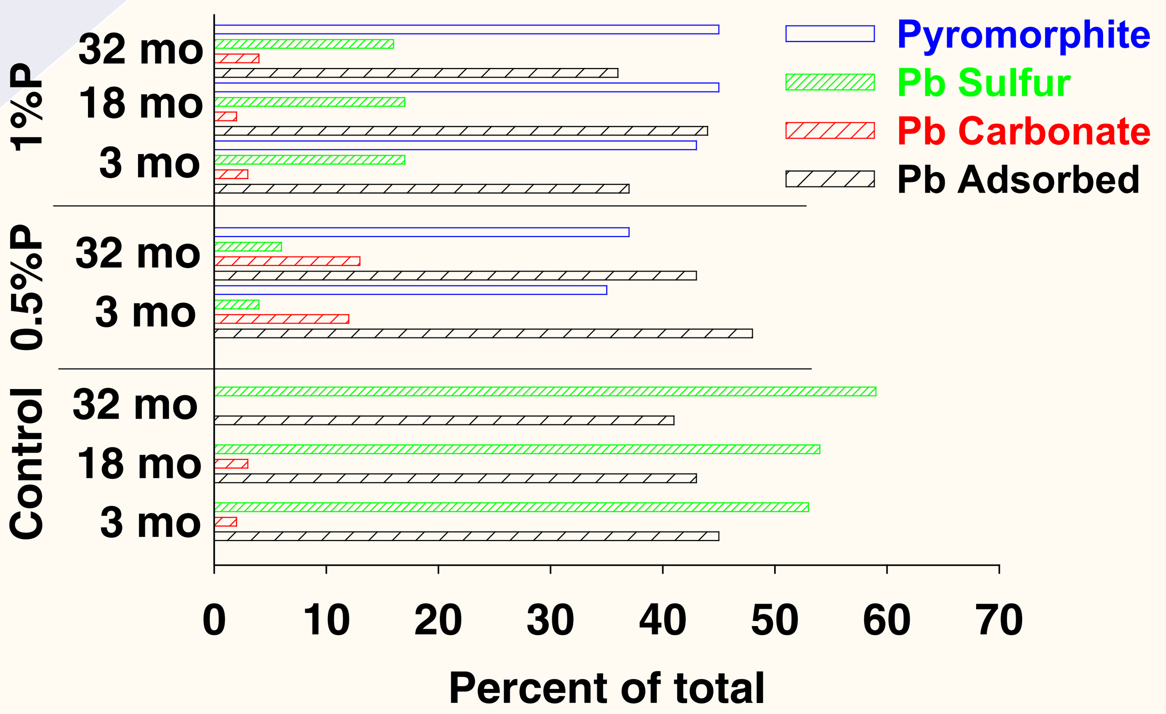

Figure 5. Lead mineral forms as a function of *in situ* phosphorus treatment and time after treatment of a lead contaminated soil.

RESULTS FROM IINERT

The swine model has been utilized by EPA to estimate site-specific oral soil Pb bioavailability (2) and was utilized in this effort. Statistically significant reductions in blood Pb in swine were observed for rate of phosphorus addition and time after addition (Figure 3). Thus, the primary hypothesis that in situ field treatments reduce soil Pb bioavailability is true. The percent reductions in soil Pb bioavailability for the 1% phosphorus treated soil was 29% for the 3 month sample and increased to 71% for the 32 month sample. The percent reduction in soil Pb bioavailability for the 0.5% phosphorus treatment was 32% for the 3 month sample and 52% for the 32 month sample.

Rat *in vivo* bioavailability assays were performed and compared with the swine in vitro assay. There were no statistically significant changes in the blood Pb response of the rats as a result of treatments; however, the data did exhibit a trend in the percent reductions in soil Pb bioavailability which illustrates that *in situ* treatments can be effective under field conditions. At the 32 month sampling there was a 40% decrease in response of the 1% phosphorus treated soil and a 23% decrease in response of the 0.5% phosphorus treated soil as compared to the control. The *in vivo* results for the rat and swine gave similar results for the 1% phosphorus treatment at the 3 month sampling whereas, for the 32 month sampling the rat *in vivo* bioavailability gave a smaller reduction than the swine *in vivo* bioavailability. Thus, the relationship between animals is less than perfect; however, both animal assays lead to the conclusion that *in situ* treatment can reduce soil Pb bioavailability.

An adult human oral bioavailability study, using a stable isotope analytical technique to measure adsorption in fasting human adults, is underway. Preliminary results for the 18 month 1% P - phosphoric acid and control soil found bioavailability was reduced 69% from an absolute bioavailability of 42% in control soil to 13% in 1% phosphorus treated soil. The human adult model provides a larger reduction in Pb bioavailability measurement than either of the other animal models. The complexity of the dissolution/precipitation reactions and the animal physiological processes involved assure that a great deal of basic research will be required before a complete mechanistic understanding can be obtained. However, we can conclude that all animal models support the conclusion that reductions in bioavailability are possible by simple *in situ* treatments. As the human model provides a measured of the greatest reduction in soil Pb bioavailability, the use of the other animal model may provide a conservative estimate of reduction.

In addition to these *in vivo* animal models, *in vitro* chemical extractions devised to imitate the physiology of human and animal digestive tracts were evaluated. Utilizing a simplified *in vitro* methodology all the soil samples from the IINERT field experiment have been measured at three extraction pH's. Results from the samples for the phosphoric acid treatments at the three sampling times are presented (Figure 4). The effect of treatment was more apparent as the pH of the extraction increased from 1.5 to 2.5; however, no effect of sampling time was observed within a phosphate rate at a pH. Thus, the *in vitro* extraction failed to predict the change in *in vivo* soil Pb bioavailability to animals associated with sampling time. Thus, extraction techniques may not be valid measures of changes in bioavailability but rather may only indicate directional changes and possibly, what change in bioavailability maybe obtained at steady state.

The issue of identification and quantification of Pb species in the complex soil matrix remains a long term research need and extends beyond the issue of soil Pb to include other metals in soil systems. Results of X-ray absorption spectroscopy (XAS) and X-ray fluorescence (XRF) microprobe analysis illustrate the addition of phosphate resulted in increased pyromorphite in the soil samples from the Joplin Site and thus provide a reason for the observed reductions in soil Pb bioavailability (Figure 5).

We conclude from the above discussion that:

1) *in situ* addition of phosphate to Pb contaminated soil under field conditions can alter the form of soil Pb and its bioavailability, and

2) it is possible to measure the bioavailability of soil Pb using animal bioassays and simple chemical *in vitro* techniques.

Thus, the basic hypothesis that under field conditions *in situ* treatments can reduce soil Pb bioavailability by changing the form of soil Pb is proven. The apparent environmental stability of the reaction products, along with the ready availability and low-cost of phosphate suggest that this approach has great merit for cost-effective *in situ* immobilization of Pb in contaminated

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